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Linbing Wang
Georgia Institute of Technology, Atlanta, Georgia

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An Anchored Band Bracing System For Deep Excavations In Clay

Linbing Wang
Georgia Institute of Technology
Atlanta, GA30332, USA

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ABSTRACT

An anchored band bracing system was introduced for the bracing of a deep excavation in hard clay with low-level expansion. In this system, stress redistribution was considered to further deduce the thickness of the surfacing shotcrete, global stability was ensured by prestressed anchors and a concrete band for the distribution of the prestress. The bracing system was shown to be cost effective and reliable under certain conditions, it is the first project using prestressed anchors combined with shotcrete for deep excavation bracing in hard clay with low level expansion in P.R. China. In this paper, the design procedure and criteria for both surfacing and global stability were summarized.

KEYWORDS: Prestress, Anchor, Excavation, Bracing, Expansive Soil, Clay, Shotcrete.

INTRODCTION

An anchored band bracing system was introduced for the bracing of a deep excavation for the underground coal transportation system of Hefei electrical power plant located at Hefei, P.R.China. The whole project includes the building of another set of steam turbine - generator system and is one of the nation's key projects. The total cost was estimated at about 600 million Chinese Yuan.

The excavation was approximately 168m long, 32m wide and 12-14m deep, it was in hard clay with low level of expansion. The bracing system was designed to protect the coal storing system and to guarantee the operations of the trains transporting coals. See the following fig.1 and fig.2 for the layout and the cross section of the project.

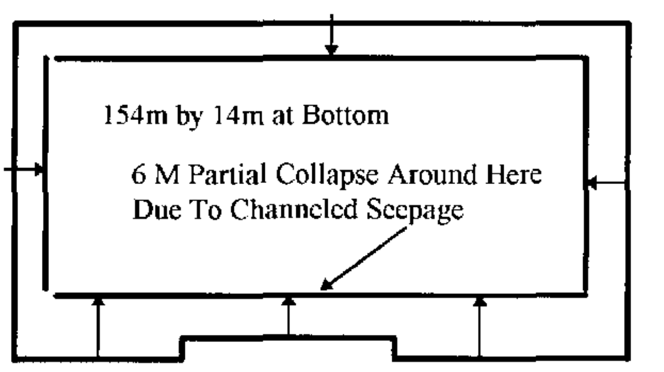

Fig.1 Layout of the Project (Not To Scale)

The closest distance between the central line of No. one train track and the slope edge is 1.25 m, the safety factor against sliding without bracing is analyzed by simplified Bishop method and is 0.98. Settlement is analyzed by finite element method and the maximum settlement is about 1.6 cm. Neither overall stability nor settlement satisfies corresponding criteria. Bracing is required. Several bracing plans were compared and the anchored band plan was adopted for its cost-effectiveness. The anchored band plan cost about 0.5 million. The other two alternatives, steel sheet pile and pre-drilled soldier piles, cost 1.8 million and 2.0

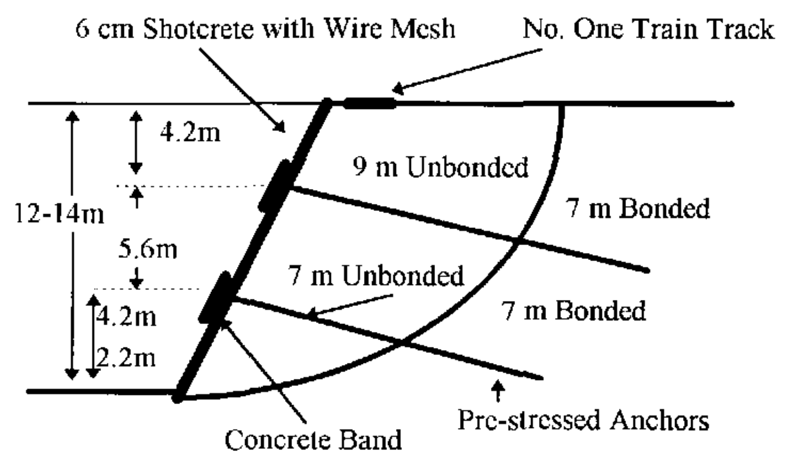

Fig.2 Cross Section of the Planed Bracing (Not To Scale)

million respectively(costs are in Chinese Yuan). The costs are compared on the assumption that the three candidates should yield the same safety factor against global sliding. However, in terms of displacement and reliability, they are not comparable. For temporary measures, displacement and reliability are considered secondary for economic reasons.

The anchored band plan consists of pre-stressed anchors, reinforced concrete bands and shotcrete surfacing (see fig.2 for details). The horizontal anchor spacing is 4 m and 3 m respectively for the middle part and the end parts. Anchors are 14 m and 16m long. The prestress is designed for 150KN. The plan yielded an overall stability safety factor of 1.28.

In this paper, the design method will be discussed. Technical considerations and decision making process will be summarized. Cause and type of a partial collapse will be analyzed, some non-technical causes will be emphasized for the attention of counterpart engineers.

BRACING MECHANISM OF THE ANCHORED BAND

The anchored band bracing system reinforces the excavated slope through three mechanisms: the increased pressure along the potential slip surface; the shear resistance of the anchors; the protection of the soil from erosion and preservation of the moisture conditions of the revealed soil and thus the minimization of the causes for expansion and shrinkage of expansive soil through shotcrete.

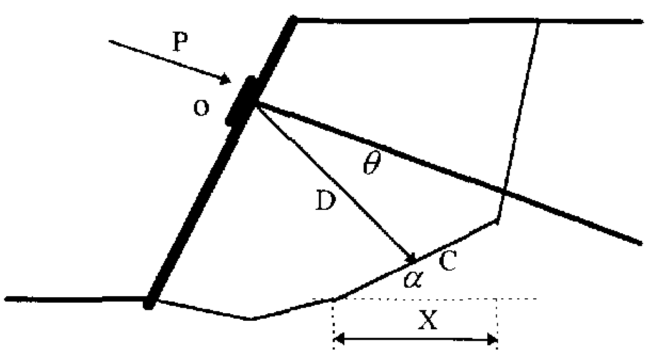

Fig. 3 Reinforcing Mechanism

Increased pressure on the potential slip surface

See fig.3, assume the horizontal anchor spacing is L, then the distributed line load intensity under a prestress of P is

$$T = \frac{P}{L} \qquad \text{------(1)}$$

Under T, the incremental stress in the soil for any point C could be approximately evaluated using Hamant formula (integrated Kelvin problem, Poulos and Davis, [1974]):

$$\sigma_r = \frac{2T}{\pi D}\cos\theta \qquad \text{------(2)}$$

where σ_r is the stress increment along CO, D is the distance between C and O; θ is the angle between CO and the direction of the force applied. C and O are the center of a slice and the center of load respectively.

The total force on the slice: $P_r' = \dfrac{2T\cos\theta}{\pi D}\dfrac{X}{\cos\alpha}$ ------(3)

where X is the horizontal projection of the slice length.

This evaluation is an approximation and thus the total force component along P direction is generally not equal to P, we must normalize the force so that they sum up to balance the applied force P. We could add the component of P_r' in P direction to get P_{sum} and obtain the normalized force along CO:

$$P_r = P\frac{P_r'}{P_{sum}} \qquad \text{------(4)}$$

This is the force that enhances the global stability. This mechanism is implemented in STABLE IV, a program developed at Purdue university. The global stability of this project is analyzed using STABLE IV.

The shear resistance by the anchors

There are several proposed methods (Juran et al. [1991]) for estimating the shear resistance by the anchors, however, it is difficult to implement these estimations for limit equilibrium analysis. The author introduced the " rule of mixture" to estimate the composite shear strength of the anchor-soil system. The " rule of mixture" estimation is only valid when the unbonded anchor length and spacing between anchors are small. In principle, when the unbonded length is large, the anchor is under bending and thus it lifts the slip surface rather than increases the stability of a certain slip surface. If the spacing is large the soil could fail between the two anchors. Actually, the shallow collapse happened in this project justified the reasoning. The influence of unbonded length and spacing between anchors on the composite strength is a good topic for further research. By the author's experience, shear resistance could be ignored when the spacing between anchors is five times larger than the anchors' diameter.

The composite strength could be estimated using the " rule of mixture":

$$\tau_{sa} = \tau_s \bullet (1 - n_a) + \tau_a n_a \qquad \text{------(5)}$$

where τ_{sa} --shear strength of the soil-anchor composite

τ_s --shear strength of soil

τ_a --shear strength of the anchor, it is the composite shear strength of the tendon and the grout and could also be

estimated using the " rule of mixture ".
n_a --area fraction of the anchors.

By this procedure, the shear resistance by the anchors are negligible for the spacing and diameters of anchors in this project.

Protection of the revealed surface

For expansive soils, surface protection and preservation of the moisture conditions of soils are very critical. Many slope projects in expansive soils failed due to the negligence of the treatment of surface soil. For expansive soil, apart from the conventional structural functions, shotcrete should have the ability to resist the expansion force from the soils. This topic will be dealt with further in the "design of surfacing" section.

DESIGN OF ANCHORS AND SURFACING

From the global stability analysis, the anchor layout, length, incident angle, prestress level are determined. For the extra loading by the train, dynamic factor was considered to be 1.1. (the train speed was limited to 5 km/hr).

Using this information, the tendons, bore hole size and bonded length are designed. In the design, available equipment is sometimes deterministic, experiences from the contractors are very valuable references.

Estimation of the pull out resistance

For short term anchors, failure could be one of the following mechanisms: failure of the soil-grout bond; failure in the soil mass; failure of the grout-tendon bond; failure of the tendons. Since tendon and grout could be controlled by design, choosing the right materials of tendon and grout could avoid these types of failure. Failure of the soil-grout bond is the most probable type. Anchor engineering practice in China also indicates, for straight shafted soil anchors, failure usually occurs at the grout-soil interface except when soil is very soft. Ultimate pull out resistance was estimated using the following formula:

$$P_{out} = \pi d L_0 \tau_{ult} \qquad (6)$$

where

P_{out} --ultimate pull out resistance; d --effective diameter

L_0 --bond length of the grouted anchor

τ_{ult} --ultimate interface shear stress and could be assessed as $\tau_{ult} = c + \sigma_{mid} \bullet \tan\varphi$; where

σ_{mid} --the vertical stress at the middle of the bond length

c, φ are respectively cohesion and friction angle of th...

For hard clay in this project, permeability of the clay is very small, the effective diameter was assumed to be equal to the bore hole diameter. The construction confirmed the validity of this assumption through the calculation of the volume of grout used.

Using the soil strength parameters, the pull out resistance per bond meter was estimated to be $30KN/M$. The ultimate pull out resistance for a designed bond length of 7 meters was $210KN$. The shear strength at the soil grout interface could reach $900 KN/M^2$. See table 1 for the design summary.

Table 1 Summary of the Design

Items	Middle Part	End Parts
Horizontal Spacing (m)	4	3
Vertical Spacing (m)	5.6	5.6
Incident Angle (Degree)	45	45
Bore Hole Diameter (mm)	110	110
Tendons ($3.4\bullet10^5$Kpa)	30(d, mm)	30(d, mm)
Design Pull Out Resistance	150(KN)	150(KN)
T Shape Band Size(cm)	100•100•30	100•100 •30

Total number of anchors: 99; Total bore hole length:1500(m)

Design of surfacing

There are two theories for the design of the surfacing, one considers the surfacing as wall panels subjected to earth pressure. The other considers the surfacing as a structural measure. We adopted the second theory. The reason is that stress redistribution is usually completed within a few days for hard clay. This phenomena was observed by displacement monitoring of several small excavations in the nearby area.

Welded wire mesh was designed for the protection of the revealed soil slope, for expansive soil this measure is very critical. However, expansion force estimated by current method is usually unrealistic, local experiences to increase the thickness of $\phi 4$ wire meshed shotcrete from conventional 40 mm to 60~80 mm plus $\phi 16$ bar at spacing of 500 mm were adopted for the reinforcement against soil expansion in this project

Design of grout

Cement sand grout was used for this project with cement-sand ratio of 1:1, and water cement ratio of 0.4. For quick strength, salt at 0.3% of cement weight, $(HOCH_2CH_2)_3N$ at 0.03% of cement weight were added to the grout. This composition proved to be effective through ...

Site testing

To verify the design estimation of the ultimate pull out resistance, two anchors were tested 20 days after the primary grouting. The first loading increment is 100 KN, reading interval is five minutes. The stability criterion is that the difference of the last two readings should be smaller than 0.5 mm. The other loading increments are 20 KN, stability criterion is the same as that of the first loading. Two criteria to stop testing were proposed: either the displacement would never reach stability or loads surpassed 240KN. The next to the last load is assumed to be the ultimate pull out resistance. For the two anchors tested, when load reached 180 KN, the displacement rate increased, and when load reached 200KN, there were earth noises happening and the tests were stopped.

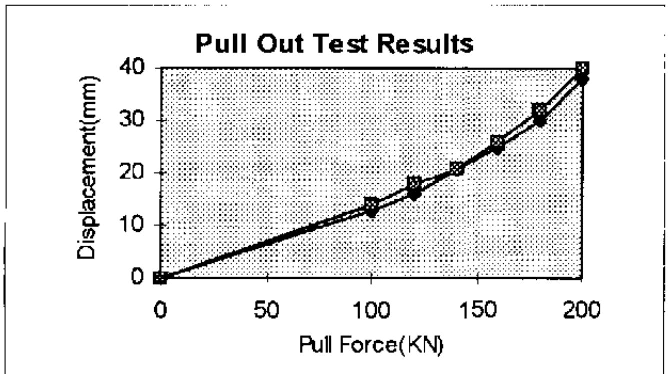

Fig. 4 Site Load Displacement Curve

The displacement and the pull out resistance curves were presented in fig. 4. Test results were very close for the two anchors. The ultimate pull out resistance was determined as 180 KN and the designed resistance was 150KN with a safety factor of 1.2. Compared with the practice here in USA, the safety factors we used for both global and local stability are a little bit smaller.

THE CONSTRUCTION

The most important quality control parameter is the incident angle. The tolerance for the angle was set for plus or minus 5 degree. Prestress was applied 28 days after primary grouting. The fill grouting was right after the application of prestress. Clayey grout was used for the fill grout. Before prestress was applied each anchor was proof tested by pulling to 180KN, 98% of the anchors were over 180KN.

DRAINING SYSTEM

According to the investigation report, ground water table is much below the excavation depth, only trenches and blockages were designed for the surface run off. During the excavation, seepage to the excavation was observed. A bore hole draining system was designed for the project. This system was never implemented by the contractor due to the better- than- expected performance of the bracing system and economic considerations. However, the fail to implement the draining system caused the partial failure at the section where significant seepage was observed.

PERFORMANCE OF THE BRACING SYSTEM

The project was planned to be completed in December, 1992, it was delayed about five months for the delay of the delivery of the equipment for the coal transporting system. Rainy season started in April. A five-day heavy rain caused a partial collapse of 6 meter section where seepage became channeled. The collapse was shallow, about 2~3 meter deep, however it tore the band to about 18 meter. Repairing and indirect loss were 180K Yuan. With that the total cost of the anchored band bracing system amounted to 400K Yuan. The other parts performed very well till the completion of the project.

The cause of the collapse is channeled seepage. For that section, soil became so soft it actually flew among two anchors. Reviewing the decision making process, two non-technical causes were related to the partial collapse. First, the design life was set to December,1992 to avoid rainy season by the administrative bureau , which was too ideal. Second, when the project performed well, the contractor took risk to save cost by intentionally delaying the implementation of the bore hole draining system.

CONCLUSIONS

Anchored band system is a cost-effective bracing system, it is paced with stage excavation and construction. Using shotcret for the surfacing tremendously reduced construction materials and the period for construction. If the construction could be well planned to avoid rainy season or a reliable draining system could be implemented. The anchored band bracing system could be applicable to hard clays with low level expansion as well .

REFERENCES

1. Ilan Juran and Victor Elias[1988]. "Ground anchors and soil nails in retaining structures" ., in *Foundation Engineering Handbook*, (H.Y. Fang, 2nd Edition) pp877.
2. H.G. Poulos and E.H.Davis [1974] *Elastic Solutions for Soil and Rock Mechanics*. pp26.